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FIELD STRESS DETERMINATIONS AT MACASSA MINE, KIRKLAND LAKE, ONTARIO

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ELLIOT LAKE LABORATORY

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by

B. Arjang* and G. Vaillancourt**

ABSTRACT

As a continuation of the stress determinations program, field stresses were measured at the Macassa Mine, Lac Minerals Ltd., Kirkland Lake, Ontario. Elastic strain recovery measurements were carried out on the 1585 m and 1890 m levels using triaxial strain cells (CSIRO, CSIR).

The maximum principal compressive stresses related to the mine grid system are oriented predominantly North-South in the horizontal plane. The minimum principal compressive stresses are oriented approximately vertical. With regard to the orientation of the orebody, σ_1, is perpendicular while σ_2 parallels the orebody.

The stress ratio, σ_{Ha}/σ_v, up to 1.5, and magnitudes of the horizontal N-S stress ranging from 1.2 to 1.6 times the horizontal E-W were determined in the test area.

The representative test values indicated that the increase of both the vertical and average horizontal stresses with depth agrees with the data obtained in Northern Ontario.

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DÉTERMINATION DES CONTRAINTES DE TERRAIN À LA MINE MACASSA, KIRKLAND LAKE (ONTARIO)

par

B. Arjang* et G. Vaillancourt**

RÉSUMÉ

Pour donner suite au programme de détermination des contraintes, on a mesuré les contraintes de terrain à la mine Macassa, Lac Minerals Ltd., Kirkland Lake (Ontario). Des mesures visant à déterminer le taux de déformation élastique ont été effectuées à l'aide de cellules de contrainte tiaxiales (CSIRO, CSIR) à des niveaux de 1585 m et de 1890 m.

Les contraintes de compression maximale les plus importantes du réseau de transport de la mine ont pour la plupart une orientation nord-sud sur le plan horizontal. Les principales contraintes de compression minimale ont une orientation à peu près verticale. Quant à l'orientation du corps de minerai, σ_1 est perpendiculaire alors que σ_2 est parallel au corps minéralisé.

On a déterminé que les taux de contrainte, σ_{Ha}/σ_v s'élevaient jusqu'à 1,5 et que la magnitude de la contrainte horizontale N-S était de 1,2 à 1,6 fois celle de la contrainte horizontale E-O dans le région où le contrôle a été fait.

Les valeurs représentatives établies lors des essais indiquent qu'un accroissement des contraintes horizontales moyennes et verticales en raison de la profondeur confirme les données obtenues dans le Nord-Ontario.

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INTRODUCTION

The Elliot Lake Laboratory, MRL, CANMET, has performed stress measurements at various localities in Northern Ontario, with the objective of assisting mine design by obtaining data on the stress regime. As a continuation of this program, a cooperative project was carried out at the Macassa Mine, Lac Minerals Ltd., Kirkland Lake, Ontario.

Field stresses were determined on two levels, 1585 m and 1890 m below surface, with an overcoring technique. The stress determination sites were selected in the development drifts, in close proximity to the proposed position of No. 3 shaft. A total of eight tests were attempted.

GEOLOGICAL SETTING

Macassa Mine of Lac Minerals Ltd. is located in Kirkland Lake, Northern Ontario. The geological setting of the deposit reflects a complex history of intermittent folding, intrusive activity, faulting or fracturing, and subsequently the deposition of the ore. The mine comprises various lenticular gold-bearing quartz veins, which are mainly associated with the fault system designated as 'Main break', or Kirkland Lake fault (1). The ore is contained in various types of intrusive rocks (syenite, syenite-porphyry) and tuff, striking NE and dipping steeply to the SE. The rock mass contains varying quantities of quartz resulting in a large variation of the elastic properties.

The ore zone extends to a depth exceeding 2000 m. Currently the active mine workings are about 700 to 1920 m below surface, and a cut-and-fill mining method is used.

FIELD MEASUREMENTS

Three-dimensional strain recovery measurements were carried out in a medium to fine-grained syenite-porphyry rock. The test sites were located away from the influence of mining. Figure 1 shows a generalized section of the mine and the levels on which tests were made.

The test holes were drilled from the mine openings, which were about 3.4 m square. In addition, the tests were commenced at distances from the walls of the openings which were greater than one or two diameters.

Field stresses were determined using the Australian CSIRO hollow inclusion triaxial strain cells. One test was carried out using a South African CSIR triaxial strain cell. Details of the overcoring test procedure and information on the technical specifications of instruments and strain cells are given in the literature (2-4). In principle, the oriented strain cell is grouted into the EX-size pilot hole which has been centrally drilled in the end of a 153 mm diameter hole. As the rock core deforms to its unstressed shape during overcoring, the strain gauges distort and their response is monitored via the read-out cable attached to the cell (CSIRO cell). Using CSIR triaxial cells, the strain changes are measured before and after overcoring, i.e., after the cell has been glued and stable readings recorded. The overcored test cell is removed from the hole, reconnected to the read-out unit and the elastic strain recovery is obtained.

Five 153 mm diameter holes with a total length of about 50 m were drilled in the test sites, but tests were performed successfully in only two holes. The locations and directions of these are shown in Fig. 2 and 3. The test holes were drilled at inclinations of 2.5° and 5° above horizontal.

On the 1585 level, no tests could be conducted in the first two holes. A joint system with slip planes nearly perpendicular to the axes of the test

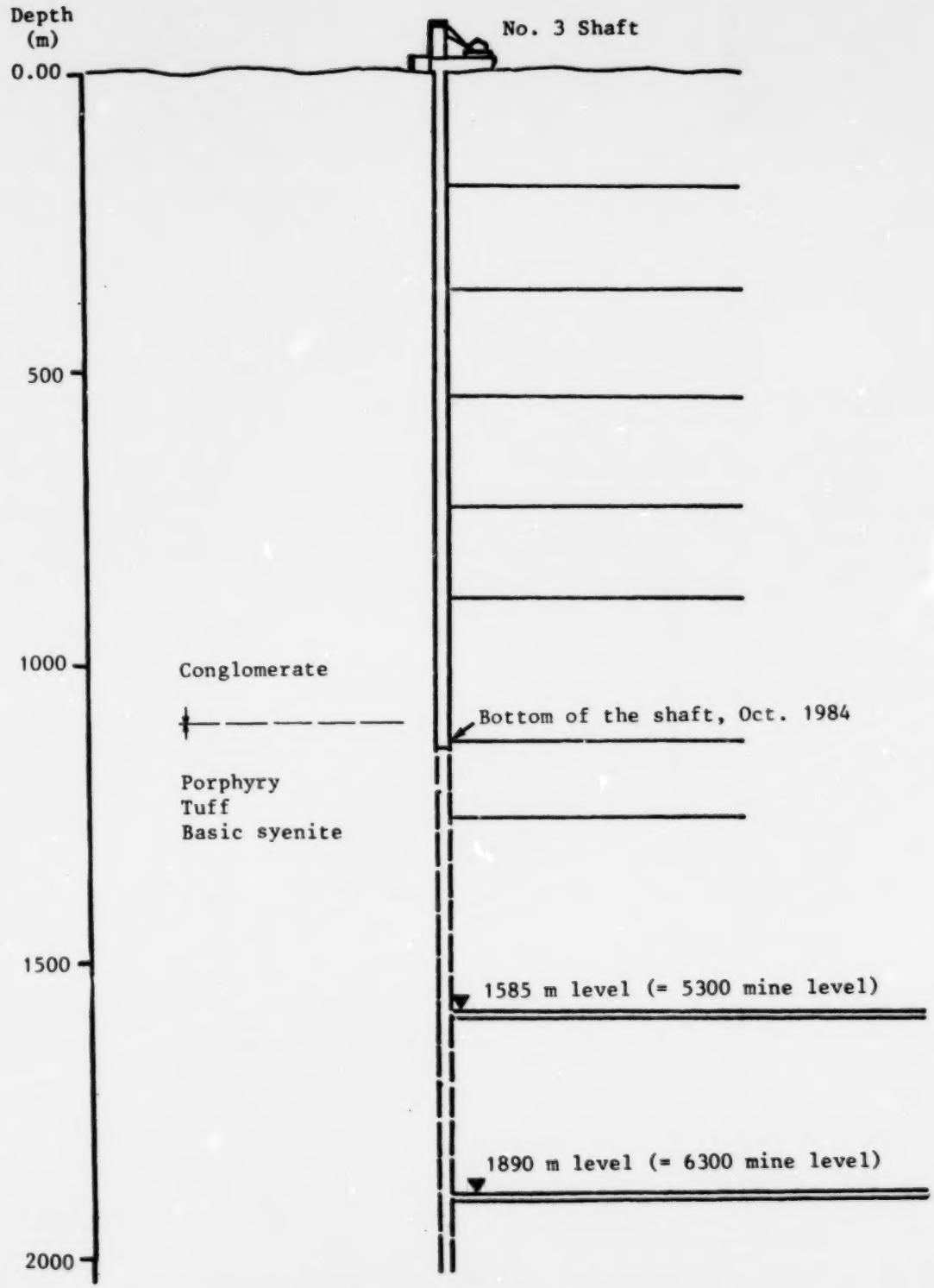


Fig. 1 - Schematic longitudinal section of No. 3 shaft, Macassa Mine, (▼) test location.

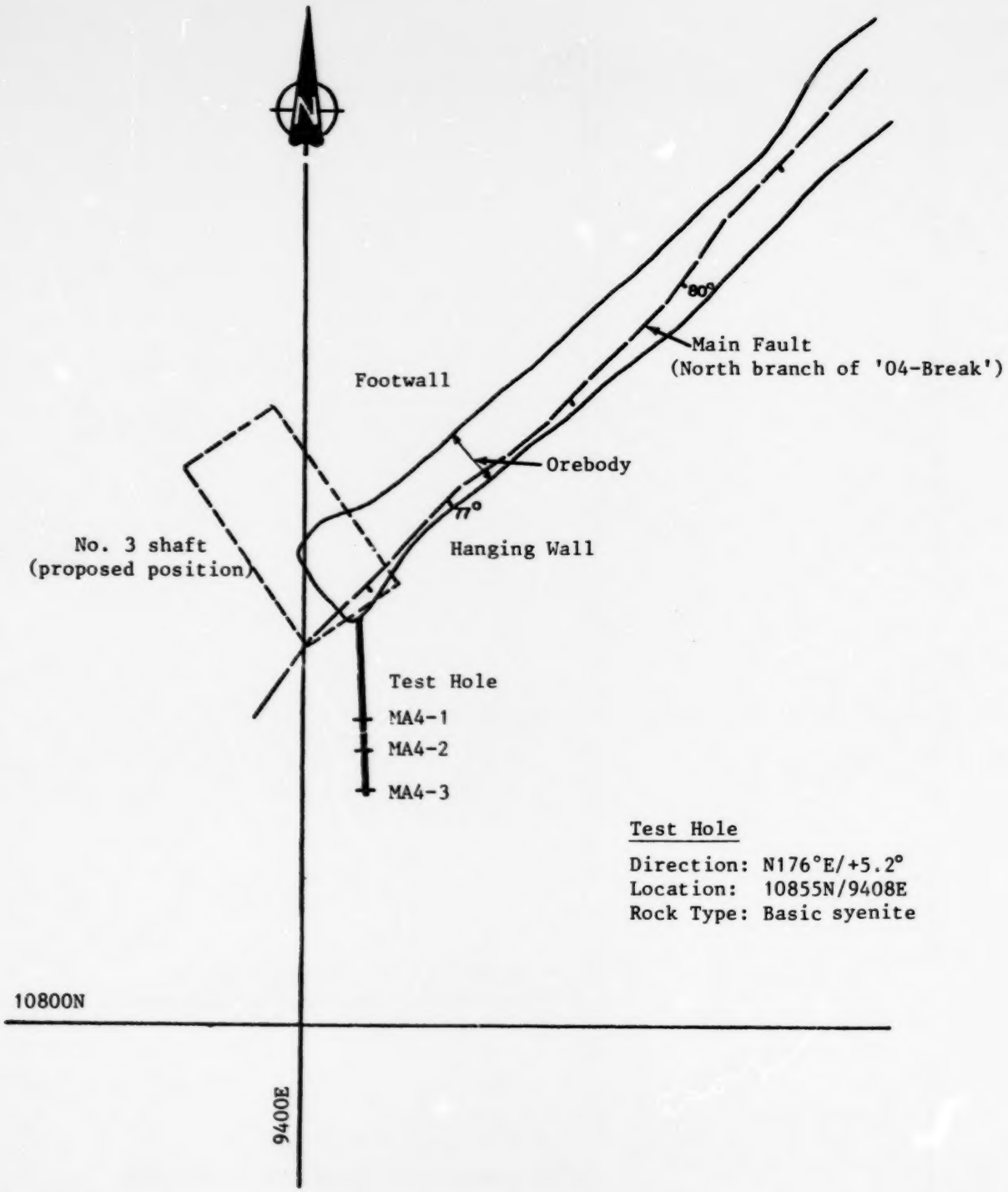


Fig. 2 - Stress determination site and test hole location on the 1585 m level, Macassa Mine (Scale 1:240).

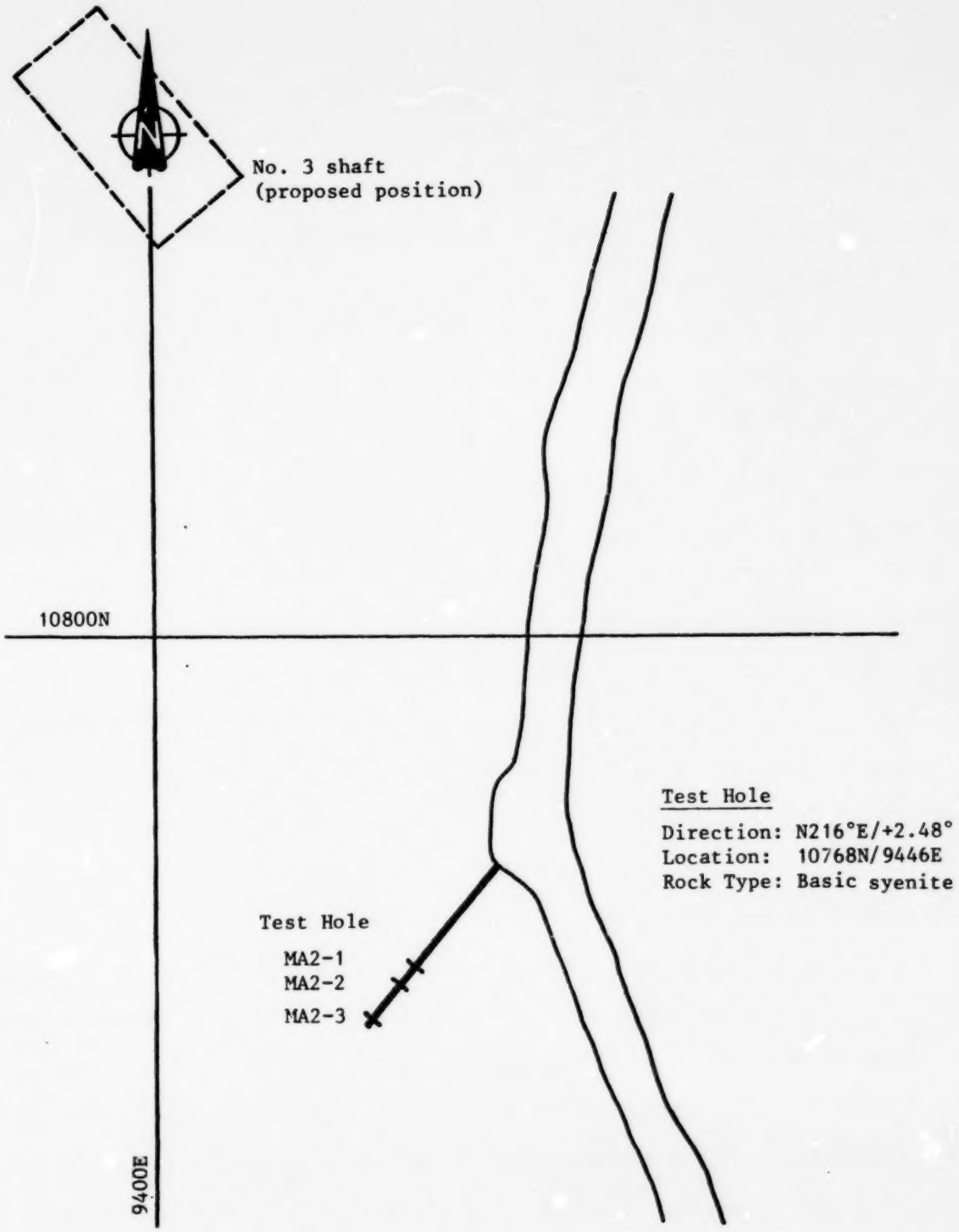


Fig. 3 - Stress determination site and test hole location on the 1890 m level, Macassa Mine (scale 1:240).

holes was encountered. This resulted in a continuous core breakage. Only one overcoring test (MA3-1) was carried out. The test was unsuccessful because the EX-hole was redrilled and enlarged, resulting in a poor bonding of the strain cell to the surface of the pilot hole. In the third hole three successful tests were performed. Similar conditions were met on the 1890 level because of the highly fractured rock.

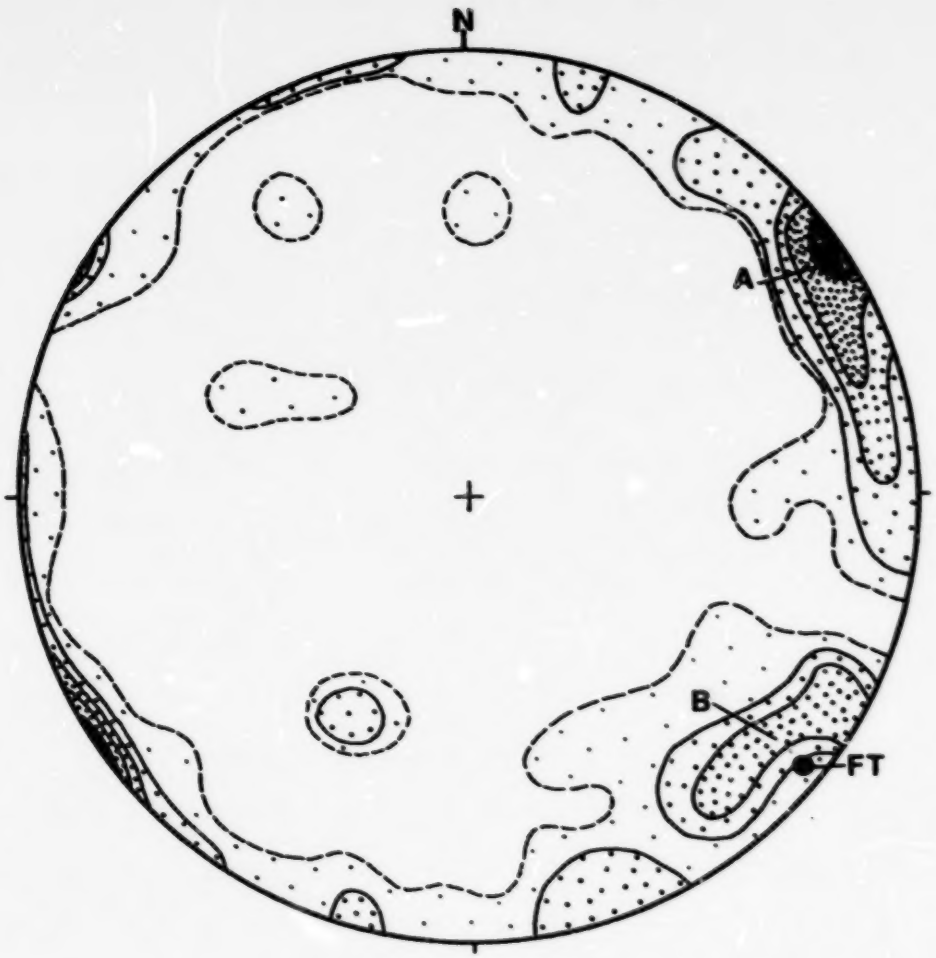
On the 1585 level, the measurements were conducted in the hanging wall of the orebody and in close proximity to a major structural weakness plane (North branch of '04 break'). In the vicinity of the test site on the 1890 level no major discontinuity was exposed.

In both test locations, stringers of quartz, or mainly quartz-filled fractures, were intermittently encountered throughout the cores. The cores represented some localized variations in the rock type, and particularly on the 1585 level where the rock appeared to be inhomogeneous.

In the vicinity of the test site on 1585 level, structural discontinuities were measured along the drift walls. Two steeply dipping discontinuity sets in NW-SE and NE-SW direction prevailed, as shown in Fig. 4. The northeasterly oriented discontinuity set parallels the major weakness plane (North branch of '04 break') exposed in the drift.

At the test sites the air temperature in drifts was between 22° and 25°C. The rock temperature was not directly measured, but it was probably in the range of 20°C. A relative humidity varying from 88% to 93% was recorded. The high humidity encountered could have influenced the measurements and the test performance, but it was not possible to assign quantitative values to such effects. However, no significant anomalous drifting of gauges or instrument malfunctions occurred during the overcoring process.

With regard to the insignificant differences between the temperature of the drill water (19° to 22°C) and the rock temperature, apparently the



Mean Orientation of Discontinuities

Set A : N146°E/82°SW

Set B : N40°E/77°NW

FT = Fault : N40°E/86°NW
(North branch of '04-break')

Fig. 4 - Stereoplot diagram of discontinuities in the vicinity of the test site on the 1585 level (53-04 drift west); contoured equal area net of lower hemisphere, frequency contours in percent per 1% area for 150 observations.

temperature equilibrium was reached during the overcoring. Some unstable strain readings were observed which were probably caused by creep of the epoxy layer due to inadequate cure or poor bonding.

Overcoring was done at a rate of about 1 cm/min. The nine channels of gauge output (CSIRO strain cells) were recorded at about 1 min intervals, using a digital strain indicator.

LABORATORY TESTING

All hollow overcored cores, containing the strain cells, were subjected to the biaxial pressure chamber to determine gauge responses and bond quality. These were subsequently axially sectioned to inspect the quality of the bond between the epoxy and the borehole surface. Minor poor bonding quality was experienced which could be related to water condensation in the pilot hole caused by the relatively high humidity in the test environment.

A successful interpretation of the results depends upon reliable values of elastic properties, as well as accurate field measurements. Based on previous experience and the test data obtained at the Macassa Mine, significant differences were noted between radial (using biaxial pressure chamber) and the axial loading of core samples to determine the elastic properties. The axial loading tests resulted in more reliable data. Therefore, representative solid core samples with a diameter of $\sim$144 mm were prepared and ground to a parallelism of $\pm$ 0.046 mm. A height to width ratio of 2.5 was maintained. Each sample was fitted with two pairs of strain gauges at mid-height in the vertical and longitudinal directions. Samples were loaded in the axial direction up to a maximum pressure of 27.0 MPa and unloaded to zero. Gauge readings in the unloading cycles were used to calculate the elastic constants. The mean values of elastic modulus were 64.33 GPA and 68.62 GPa, and Poisson's ratios were 0.16 and 0.19, for the core

samples from the 1585 and 1890 test locations, respectively. These were used for the stress tensor calculations. Some test samples contained various quartz-filled fractures, resulting in variations in the elastic properties.

Uniaxial compressive strengths were obtained on EX-size cores from the stress determination holes. These ranged from 166 MPa to 245 MPa, with a mean value of 211 MPa.

STRESS CALCULATIONS

A composite strain recovery by overcoring, the elastic constants, and the test hole orientation in the mine grid system were taken as input data for the stress tensor calculations. The data were processed by a computer program calculating the magnitudes and orientations of the principal stresses along with resolved vertical and horizontal stresses and relevant statistical information (5,6). The calculation results in the tensor of the best fit according to a least squares solution.

The elastic strain recoveries , the test hole orientations, the setting depth of the strain cells, and the elastic constants are given in Table 1. Table 2 provides the calculated ground stress tensor in relation to the mine grid system, N-S, E-W, vertical, shear stresses and the principal stess magnitudes and orientations.

Figures 5 and 6 give the orientation of the principal stresses in the lower hemisphere of an equal area net. The plots of gauge responses and the changes in micro-strain are shown in the Appendix.

With reference to the strain readings, it was observed that in some tests the gauges displayed strain relief and erratic response at 15-20 cm (distance from the cell centre location) before the strain cell (CSIRO) was overcored. It appeared that the strain readings after commencement of overcoring, at about 1 cm of overcored distance were more reliable.

Table 1 - Strain recovery data from triaxial strain cell measurements, Macassa Mine.

Location	Test No.	Test Hole Bearing/Dip (1)	Setting Depth from Collar (m)	Elastic Strain Recovery ($\mu\varepsilon$) Gauge No: 1	2	3	4	5	6	7	8	9	Elastic Modulus (Gpa)	Poisson's Ratio
1585 m level	MA3-1	130/-6	8.52	Test unsuccessful										
	MA4-1	176/-5	4.34	769	796	872	1138	(2)	1237	581	1519	1002	64.33	0.16
	MA4-2	176/-5	5.70	339	511	545	1370	710	2059	554	1418	615	64.33	0.16
			Gauge No:	1	2	3	4	5	6	7	8	9	10	11	12		
	MA4-3(3)	176/-5	7.00	865	815	915	1015	850	865	425	455	740	775	510	925	64.33	0.16
	MA-5	185/-3	-	No Tests													
1890 m level	MA1-1	350/-3	5.87	Test unsuccessful										
	MA2-1	216/-2.5	5.70	723	1051	866	1642	1969	2280	765	1884	1000	68.62	0.19
	MA2-2(4)	216/-2.5	6.40	543	585	918	1013	570	1050	391	1274	564	68.62	0.19
	MA2-3	216/-2.5	8.23	895	837	1179	1886	1375	2349	860	1869	803	68.62	0.19

(1) Bearing in degrees clockwise from grid north positive; dip in degrees (dip from horizontal, positive down).
(2) Erratic gauge response; omitted from stress calculations.
(3) South African CSIR triaxial strain cell.
(4) Core broke at 34 cm distance from EX-collar during overcoring.

Table 2 - Stress components, magnitudes and orientations of the principal stresses from triaxial strain cell measurements, Macassa Mine.

Location	Test No.	Stress Components (MPa) (Standard errors in brackets)						Principal Stresses Magnitude (MPa) Bearing/Dip*		
		Horizontal			Shear Stress					
		N-S	E-W	Vert.	NS/EW	EW/V	V/NS	σ_1	σ_2	σ_3
1585 m Level	MA4-1	64.16	40.40	38.88	-6.59	-6.77	5.07	67.45	43.18	32.81
		(4.98)	(1.88)	(1.97)	(2.45)	(1.32)	(2.31)	163/-13	062/40	088/47
	MA4-2	46.27	53.06	31.81	-7.77	-8.92	6.43	62.20	41.21	27.73
		(.37)	(.14)	(.15)	(.18)	(.10)	(.17)	124/-20	215/-2	311/-70
	MA4-3	52.84	33.70	30.33	0.50	-3.05	4.48	54.12	33.56	29.19
		(6.01)	(3.66)	(3.66)	(2.09)	(3.04)	(3.04)	168/10	261/16	046/71
1890 m Level	MA2-1	80.69	61.06	50.86	0.36	-3.29	9.07	83.24	61.84	47.54
		(.23)	(.19)	(.11)	(.14)	(.07)	(.13)	179/-16	085/-13	318/-70
	MA2-2	66.09	39.28	35.19	13.13	1.74	13.87	75.95	36.10	28.51
		(3.75)	(1.75)	(1.20)	(2.37)	(.77)	(1.45)	021/18	280/30	317/-54
	MA2-3	79.73	67.79	48.38	3.75	1.19	17.92	88.59	67.06	40.24
		(2.24)	(.80)	(.68)	(.87)	(.42)	(.76)	012/24	280/5	358/-66

* The bearing is the angle in degrees positive clockwise from grid north; dip is the angle in degrees positive down from horizontal.

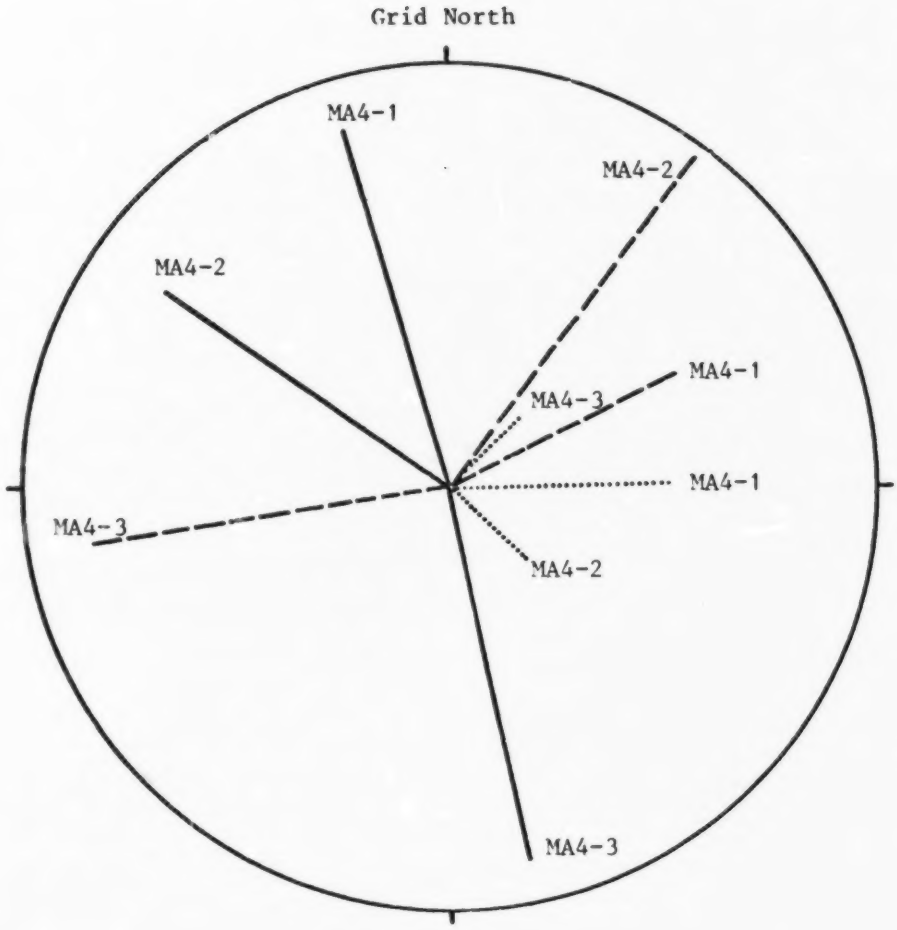


Fig. 5 - Orientation of principal stresses from grid north on the 1585 level in an equal area net, lower hemisphere projection, (Grid north = true north).

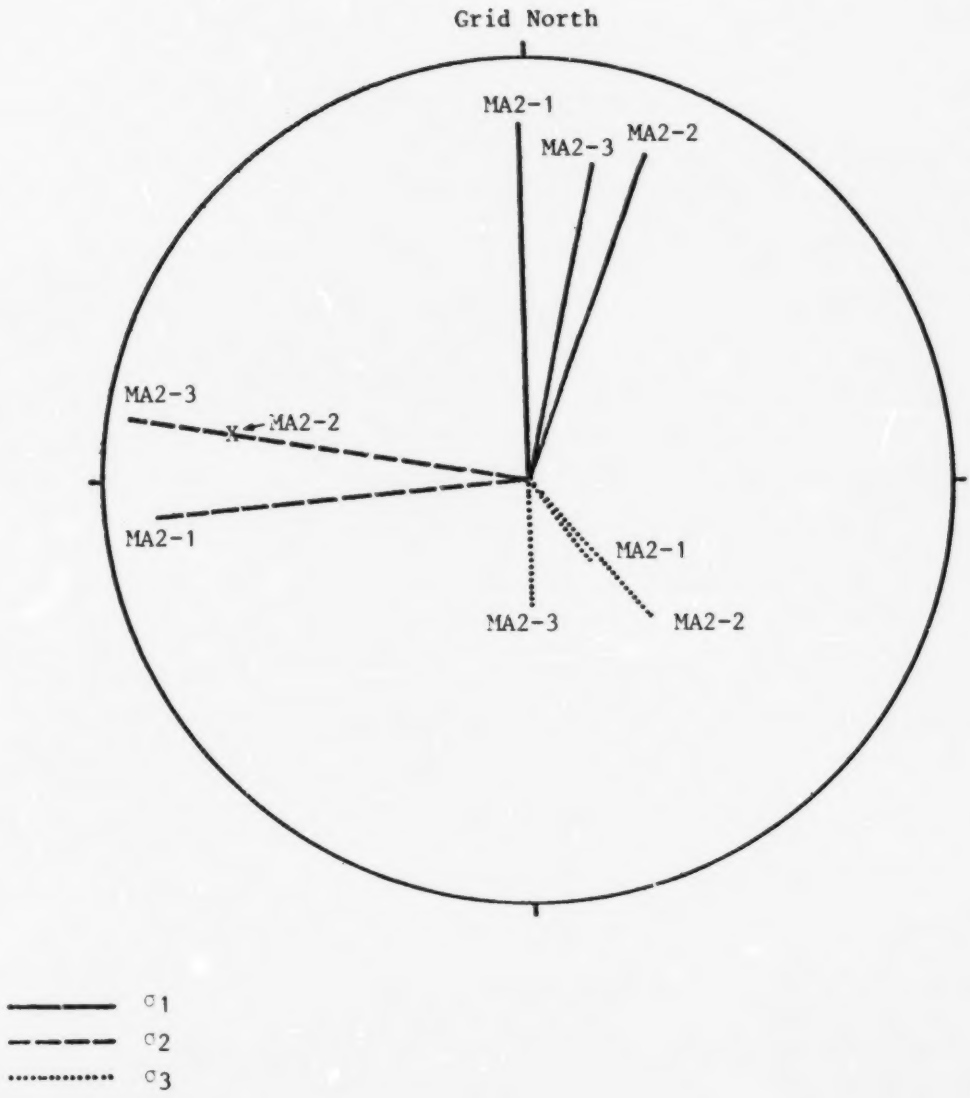


Fig. 6 - Orientation of principal stresses from grid north on the 1890 level in an equal area net, lower hemisphere projection, (Grid north = true north).

Therefore, strain differences between these readings ('initial readings') and the stable readings after the cell centre location were used for stress calculations.

DISCUSSION OF RESULTS

For each stress determination site the direction of the principal stresses are rather stable, but when comparing both sites the orientations of the principal stresses indicate some variations. On the 1585 level, the major principal compressive stress, σ_1, is oriented NW, and on the 1890 level in a NNE direction. The intermediate principal compressive stress, σ_2, shows NE-SW and E-W orientations on the 1585 and 1890 levels, respectively. Both σ_1 and σ_2 are within a horizontal plane. The minor principal compressive stress, σ_3, is nearly vertical with a southeasterly orientation.

Structural surveys in the vicinity of the test site on the 1585 level suggested that a relationship between the prevailing orientation of the joint system and the direction of the principal stresses exists. The joint set A (NW-SE) is in the direction of the major principal stress, whereas the joint set B (NE-SW) tends to be parallel to the orientation of the intermediate principal stress.

Measurements on the 1585 level show a rather variable stress field, where a higher horizontal E-W stress than the N-S stress was measured in the MA4-2 test. This appeared to be anomalous, compared to the remaining data, and probably reflects the influence of the weakness planes which occurred in the test hole.

After screening the stress determination tests, the most representative values were summarized. Table 3 shows the magnitudes and overall orientation of the principal stresses with respect to grid north, as well as the stress ratios and the mean stresses.

Table 3 - Magnitudes and overall orientations of the principal stresses

Location	Test No.	Principal Stresses Magnitude (MPa) and Orientation						Stress(*) Ratio	Mean Stress (MPa)
		σ_1		σ_2		σ_3			
		Mag.	Orientation	Mag.	Orientation	Mag.	Orientation	$\sigma H/\sigma_v$	$\sigma_1+\sigma_2+\sigma_3/3$
1585 m level	MA4-1 MA4-3 Camb.	60.80	NNW-SSE/horiz.	38.40	ENE-WSW/sub-horiz.	31.00	ENE-WSW/vertical	1.27	43.40
1890 m level	MA2-1 MA2-3 Camb.	85.90	NNE-SSW/horiz.	64.45	E-W/horiz.	43.90	NNW-SSE/vertical	1.47	64.75

(*) $\sigma_H/\sigma_v = \frac{\sigma_1+\sigma_2/2}{\sigma_v}$; the maximum values of measured vertical stress components of σ_v = 39.00 MPa (1585 level) and σ_v = 51.00 MPa (1890 level) were used for calculations.

Based on the final results, the mean vertical stress gradient amounted to 0.0246 to 0.027 MPa/m, and the average horizontal stress gradient was in the range of 0.031 to 0.040 MPa/m. The increases in the vertical stress and the average horizontal stress with depth follow the trends reported elsewhere in Northern Ontario (7).

The values obtained from the measurements at Macassa Mine are regarded as acceptable estimates of the in situ stress. However, the results are difficult to extrapolate in a regional scale of the mine because of geological features, and variations in the elastic properties and the strength of the rock types. Additional testing at different locations will be necessary to establish more reliable quantitative information.

CONCLUSIONS

From the completion of the ground stress determinations the following major points can be concluded:

1. The stress magnitudes obtained at Macassa Mine were similar to those found elsewhere in Northern Ontario. Regarding the orientation, the maximum principal compressive stress varies from the prevailing E-W trend. This is probably indicative of the structural evidence at the stress determination sites.
2. The maximum pre-mining stress is in a horizontal plane with a NNE-SSW to northwesterly direction. In regard to the orientation of the orebody, σ_1 is nearly perpendicular while σ_2 parallels the orebody.
3. The horizontal stress is higher than the vertical, whereas the vertical component of the in situ stress approximates the overburden weight. The ratio of the average horizontal stress to vertical stress ranges from 1.27 to 1.47. The magnitude of the horizontal N-S stress 1.2 to 1.6 times the horizontal E-W stress was determined.

4. From the gound stress determinations, the pre-mining vertical stress, as well as the horizontal stresses perpendicular and parallel to the orebody can be approximated as follows:

vertical stress = 0.026 MN/m^3 x depth (m) in MPa

perpendicular σ horizontal = 1.56 to 1.68 x vertical stress

parallel σ horizontal = 1.00 to 1.27 x vertical stress

Regarding the varying elastic properties and the strength of the rock types as well, some distortions in the stress values obtained can be expected.

ACKNOWLEDGEMENTS

The cooperation of Lac Minerals Ltd., especially G. Nemcsok, Chief Area Geologist, and the assistance provided by R. Hong, Macassa Mine, is appreciated.

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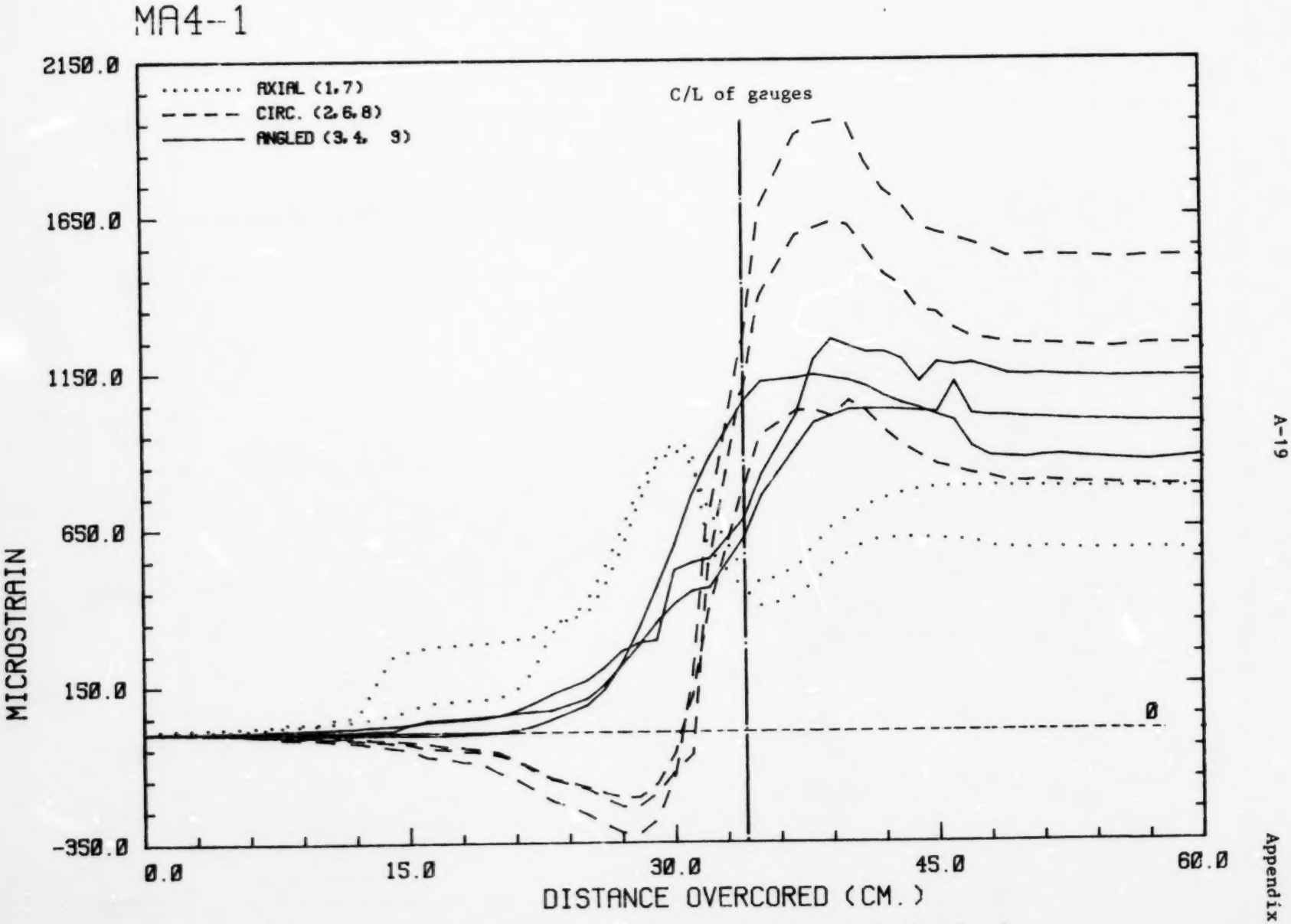

Fig. A-1 - Overcoring response of gauges in test MA4-1, on the 1585 level.

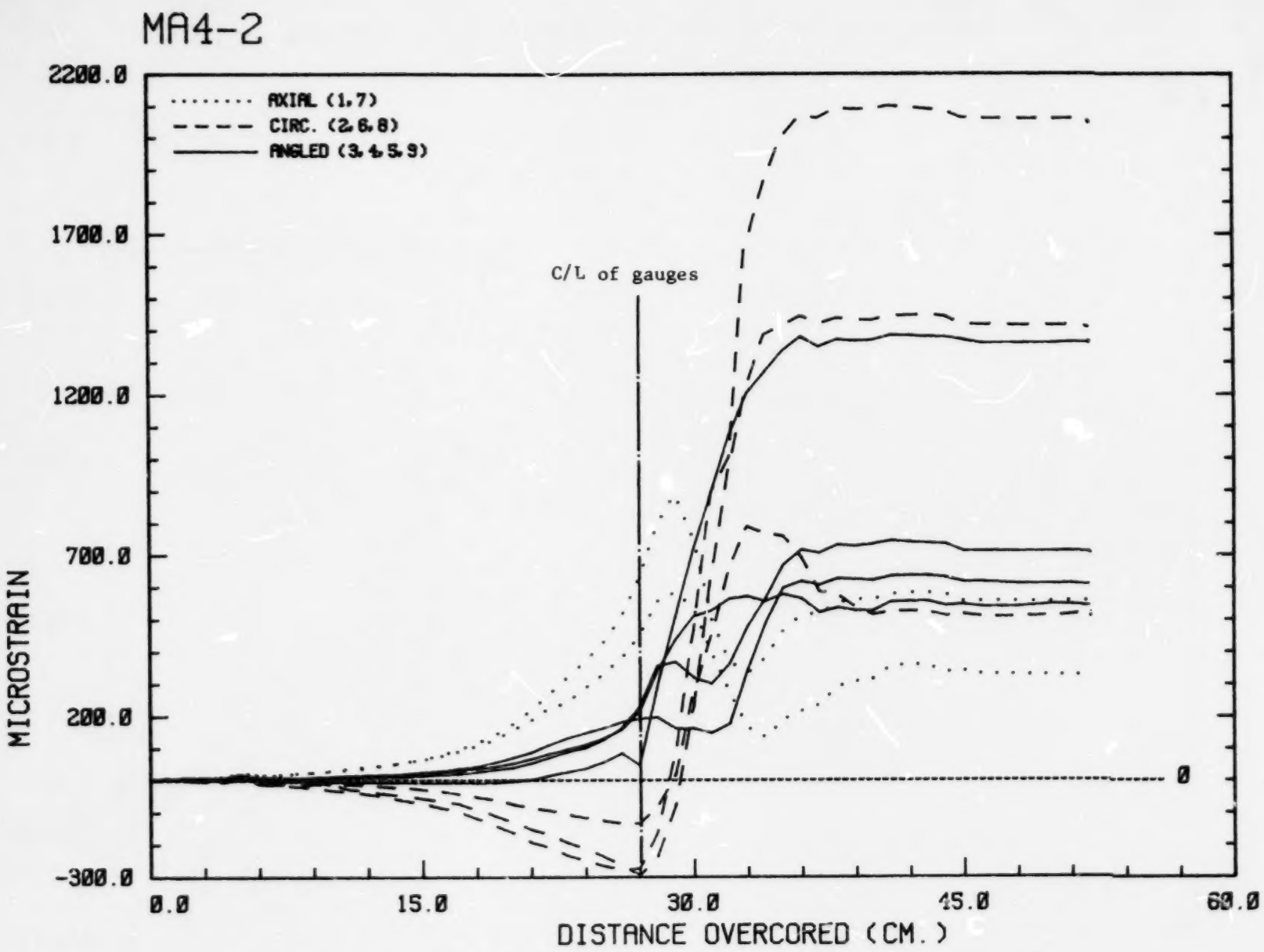

Fig. A-2 - Overcoring response of gauges in test MA4-2, on the 1585 level.

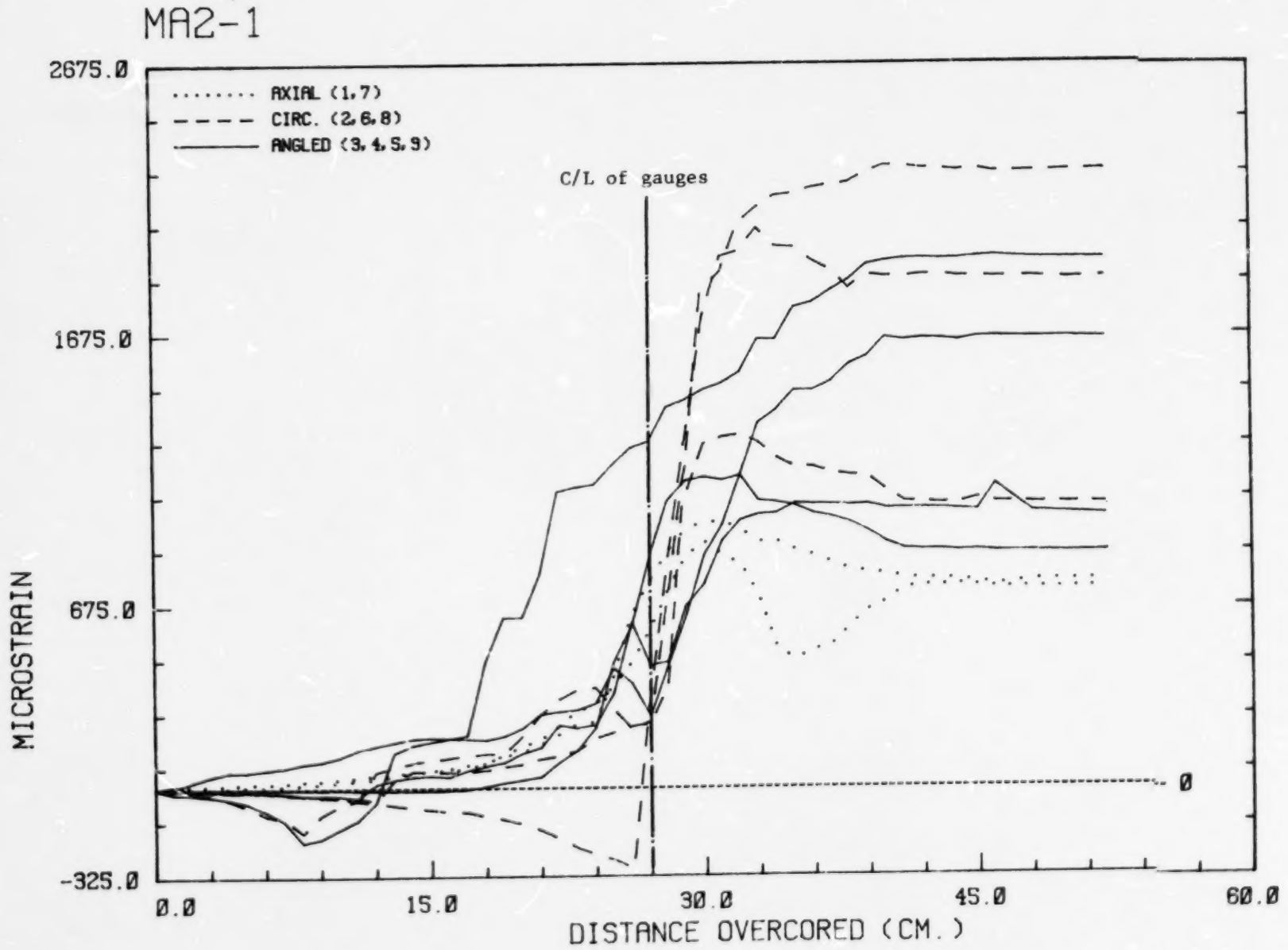

Fig. A-3 - Overcoring response of gauges in test MA2-1, on the 1890 level.

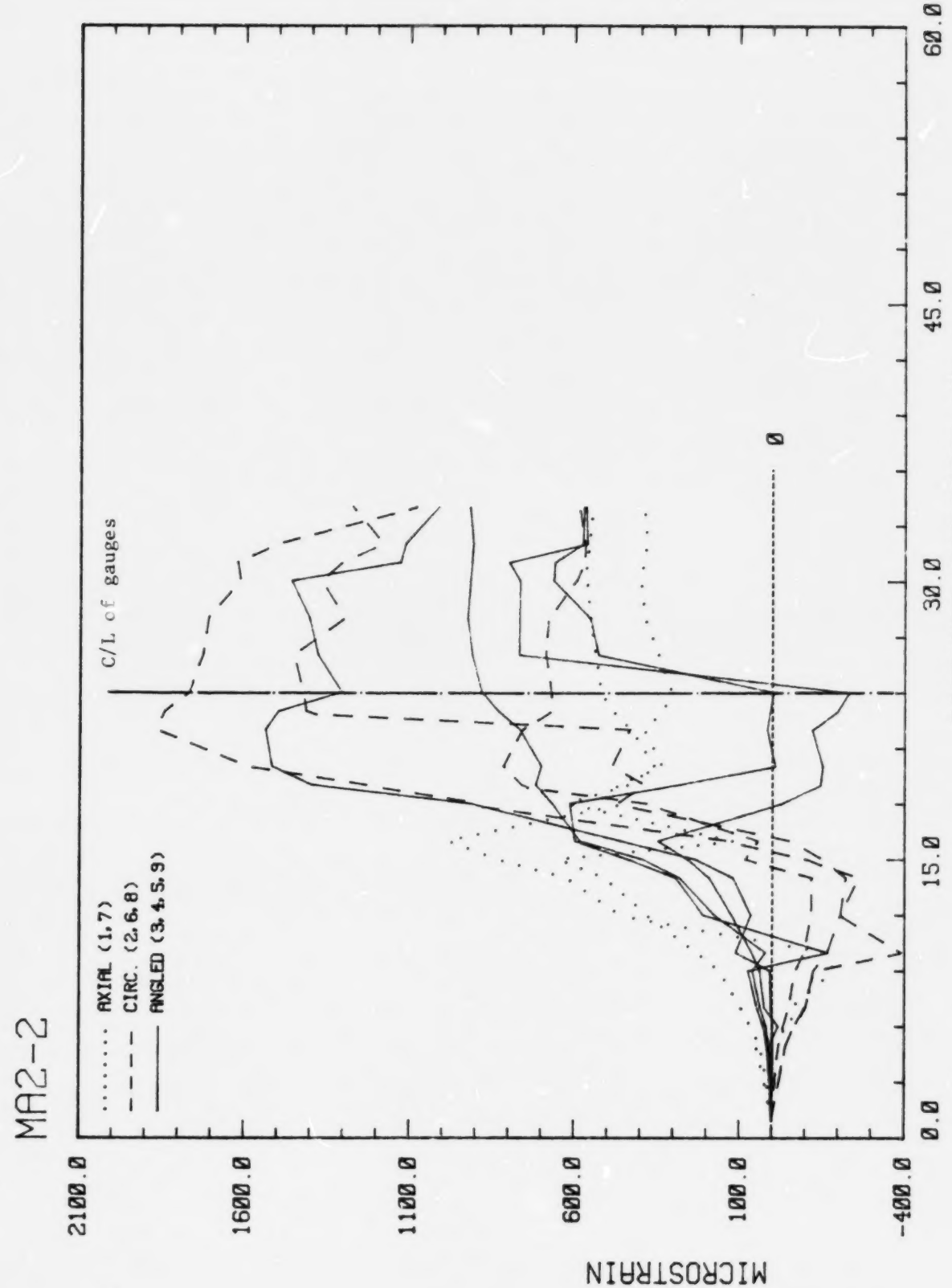

Fig. A-4 - Overcoring response of gauges in test MA2-2, on the 1890 level.

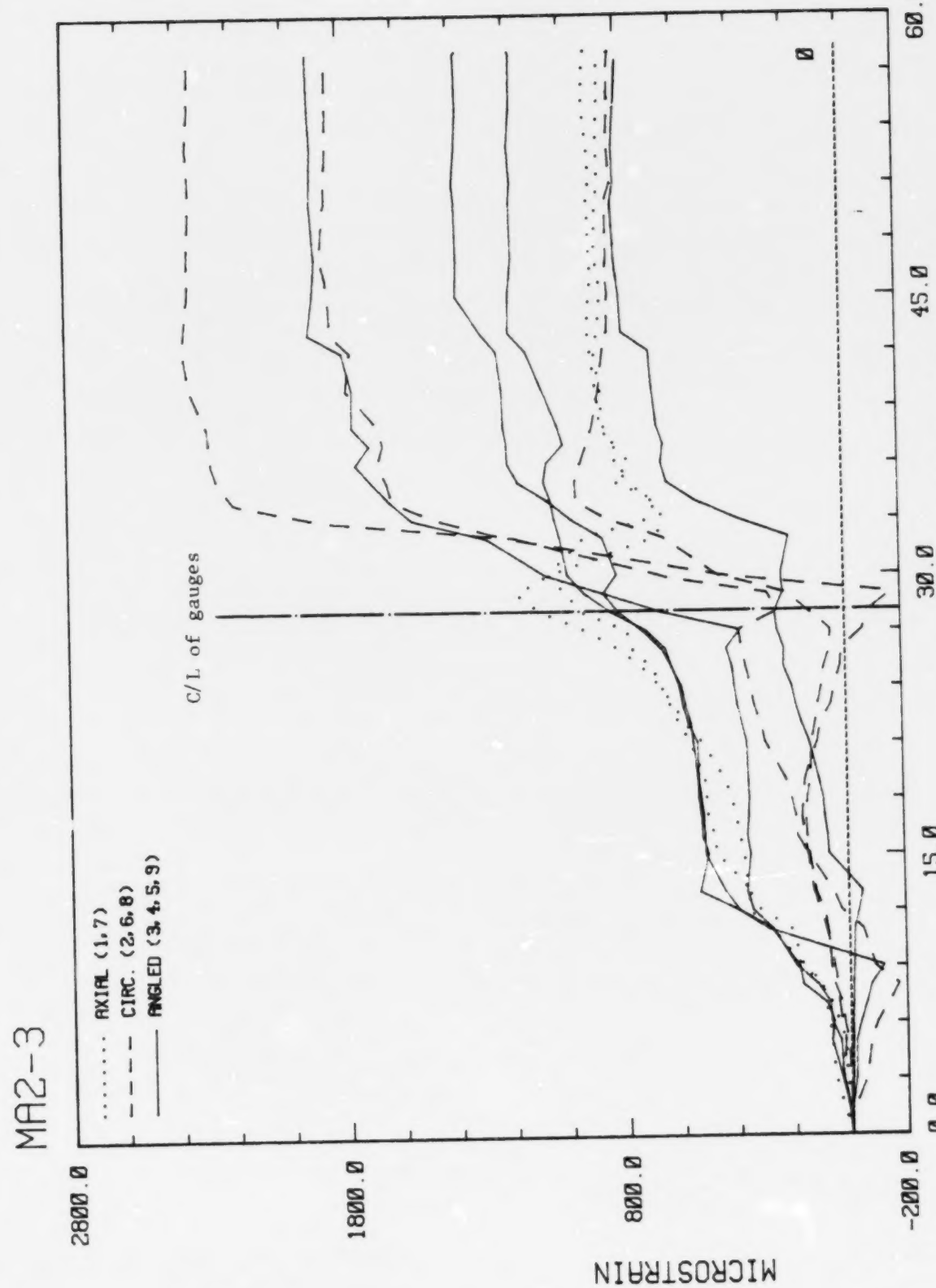

Fig. A-5 - Overcoring response of gauges in test MA2-3, on the 1890 level.